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USERS' GUIDE

to Debris Prediction and Hazard Appraisal

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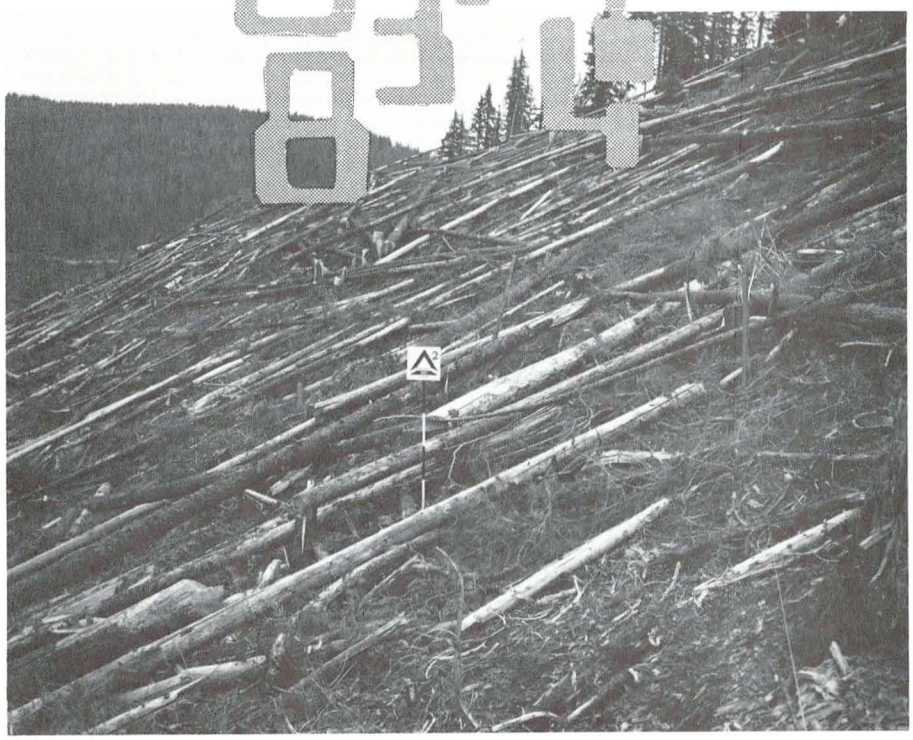

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USERS' GUIDE
TO
DEBRIS PREDICTION AND HAZARD APPRAISAL

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Preface

The purpose of this publication is to guide the application of recent research results to the solution of a specific forest management problem--fuel management. Field managers do not need to exercise unusual technical skills to use the debris prediction and hazard appraisal technique; and, although the technique is computerized experienced field judgment is essential for proper interpretation and application of results.

The debris prediction and hazard appraisal technique is intended for use during the planning stage of forestry operations that involve the cutting of trees. If used in this manner, on-the-ground management of forest residues in the northern Rocky Mountains can be improved significantly.

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March 1977

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TABLE OF CONTENTS

	Page
Preface	*ii*
Acknowledgments	*iii*
I. INTRODUCTION	1
USES OF DEBRIS PREDICTION	1
USES OF FIRE BEHAVIOR PREDICTIONS	2
II. OBTAINING DEBRIS AND FIRE BEHAVIOR PREDICTIONS	4
BASIS FOR DEBRIS PREDICTION	4
ACQUIRING THE DEBRIS PRINTOUTS	6
DEBRIS PREDICTION DEFINITIONS	6
SUMMARIZING DEBRIS BY CUTTING PRESCRIPTIONS	9
ACCURACY OF DEBRIS PREDICTIONS	11
EXAMPLE OF SUMMARIZING DEBRIS	11
COMPLETING THE HAZARD FORM	20
OTHER DEBRIS PREDICTION METHODS	22
SUMMARY OF STEPS TO PREDICT DEBRIS	23
III. EXPLANATION OF FUEL AND FIRE OUTPUTS	25
FUEL	25
FIRE BEHAVIOR	28
LIMITATIONS AND ACCURACY	31
Basic Assumptions	31
Accuracy of Predictions	32
IV. SUMMARY	35
REFERENCES	36

I. INTRODUCTION

This guide describes a technique that can help managers make better decisions about woody debris. The word "debris" is used here to describe dead tree branches, boles, twigs, and leaves on the forest floor. This woody material can result from natural processes or from forestry operations. Other words that are often used for the same purpose are fuel, slash, brush, and residue. The technique predicts the amount of debris that will result from a planned cut. The potential fire behavior of the predicted debris is also estimated. The technique is important because decisions can be made before any trees are cut.

The technique is easy to use. Existing computer programs for processing stand exams are used to predict debris from planned "cut" trees. The predicted debris is added to the debris already present on the area, and fire behavior estimates are given for the entire "fuel" complex. Fire behavior is evaluated for several wind speeds, based on specified top diameter limit, skidding method, and cutting scheme.

The results of several recent fire research studies provide the basis for this technique. Brown's (1974, 1977) work in fuel inventory and debris prediction provides the basis for the debris estimates. Rothermel's (1972) mathematical model for fire spread and Albini's (1976) computer-based fire behavior models form the basis for the fire behavior estimates. One new study was necessary in order to find out how to predict debris depth from debris amount (Albini and Brown 1978).

This guide is designed for use by National Forest managers in the Northern Region, USDA-Forest Service. Other managers of similar forest cover types may be interested in applying these techniques. They should contact Northern Region Fire and Aviation Management, P.O. Box 7669, Missoula, Montana 59807.

USES OF DEBRIS PREDICTION

The debris prediction part of the technique describes the amount of debris that will result from trees selected for cutting. The average depth of the resulting debris is estimated for a 5-year-period after cutting. Part II of this guide describes in detail the debris predictions provided and explains how to get them.

Debris prediction gives fire managers and resource managers a better way to discuss debris--and it allows them to do so before it is created! Fire managers can deal more effectively with resource managers regarding fuel management needs connected with planned forestry operations that involve cutting trees. The size and

amount of debris likely to result from various management options can be stated in terms of probable values. Thus, objective decisions about debris are possible.

The debris prediction technique can aid in planning forestry actions that create debris. The timber sale planner, for example, can state in numbers the size and amount of debris likely to result from a silvicultural prescription and associated logging plan. More definite debris disposal plans and contracts can be written, and more precise production rates and costs can be computed. Improved burning prescriptions for hazard reduction and site preparation can result from using debris estimates. Both the total load and the amount of 3-inch debris are critical for selecting the proper range of fuel moisture needed to accomplish burning objectives (Norum 1977). *(CAUTION--the fire behavior predictions given by the hazard appraisal technique may not be suitable for planning prescribed fire, because they predict only for head fires and do not contain estimates of fuel consumption. The debris predictions together with guides such as Norum's should be used for planning prescribed fire.)*

Predicted volumes of debris reflect the fiber potential of logging or thinning leftovers. These predicted volumes can help in setting timber sale utilization standards. Estimates of the amount of sound dead wood, by size class, can also be used to decide if a dead wood sale might be an appropriate means of fuel reduction.

USES OF FIRE BEHAVIOR PREDICTIONS

The hazard appraisal part of the technique describes the potential fire behavior associated with the predicted debris. Moisture content of fuels can be specified; otherwise, severe fuel moisture is assumed (1-hour timelag fuel moisture--5 percent). Fire behavior estimates are given for a range of windspeeds (0 to 20 mi/h) and for 1, 3, and 5 years after debris is created. The fire behavior estimates include:

1. Head fire spread rate
2. Perimeter growth rate
3. Burned area after 1 hour
4. Head fire flame length
5. Crown scorch height by head fire
6. Intensity at head of fire
7. Heat load of residual fire from burnout of larger fuels and duff
8. Burn time of residual fire.

Values for the above fire behavior elements are given for each specified cutting scheme, skidding method, and utilization standard. Also, the effect of lopping slash to a 2-foot standard depth is given. Part II of this guide explains how to obtain the fire behavior values listed above. These fire behavior elements are described in detail in Part III of this guide as are aids to interpret the fire behavior numbers.

Hazard appraisal estimates allow the manager to study the effect of forestry practices on potential fire behavior. The manager can make separate computer runs using different combinations of cutting schemes, utilization standards, and skidding methods to answer such questions as:

- What is the effect of changing utilization standards from a 6-inch top to a 3-inch top on potential debris and associated fire behavior?

- What is the effect of changing skidding method from ground lead to skyline on potential debris and associated fire behavior.

- What is the effect of changing number of leave trees per acre from 300 to 500 on potential debris and associated fire behavior?

The answers to these kinds of questions, properly interpreted, can provide an objective basis for improved debris disposal decisions for planned forestry operations. The fact that the decisions can be made before any trees are cut adds to the significance of the technique as a fire and resource management planning tool.

II. OBTAINING DEBRIS AND FIRE BEHAVIOR PREDICTIONS

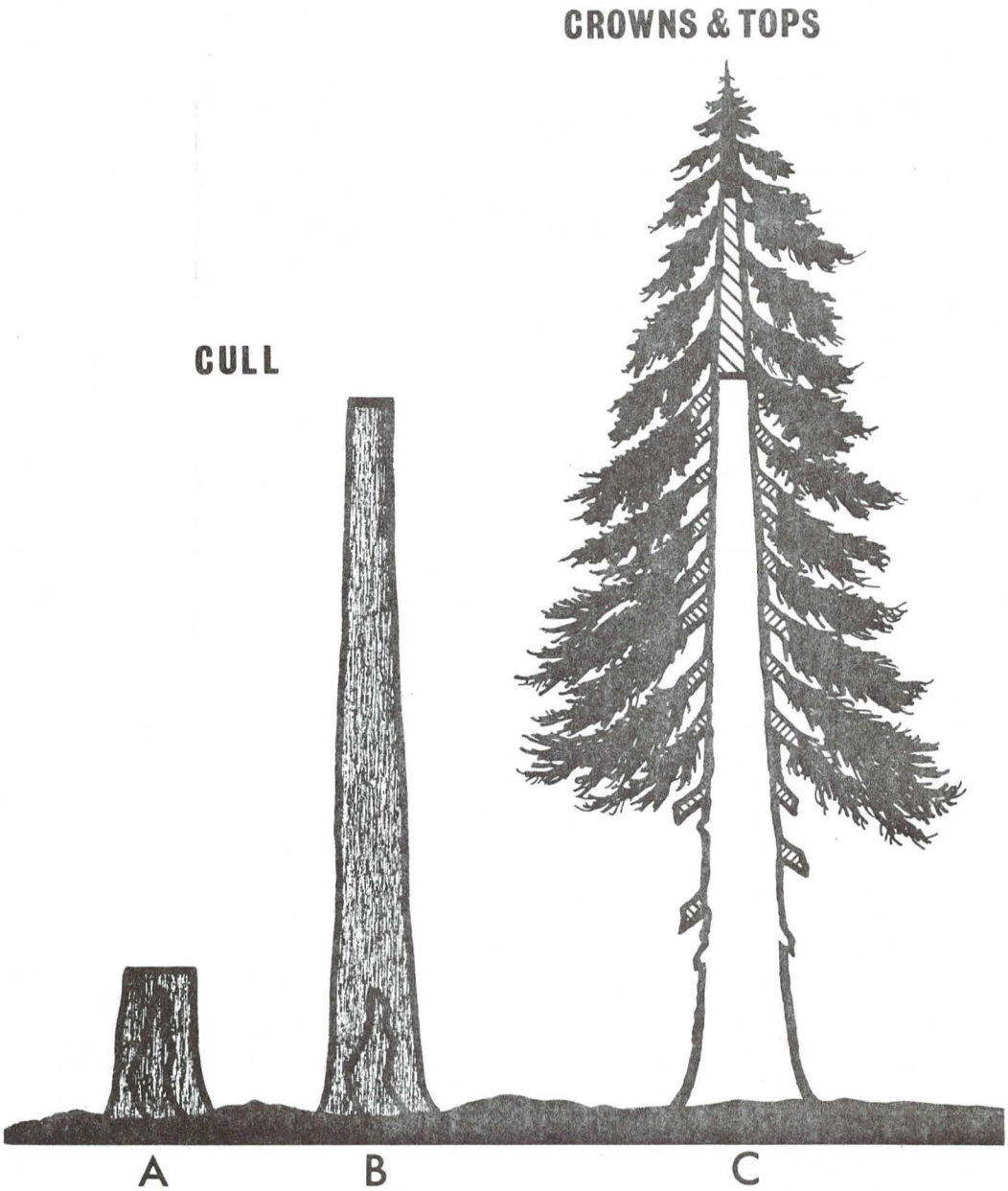
To get fuel and hazard estimates, two computer programs are operated. One program predicts debris (called DEBMOD) and the other predicts fire behavior (called HAZARD). To predict debris a tree inventory is needed. The debris prediction program described here uses the Northern Region's stand exam inventory (sometimes called Stage I inventory). Once the debris is predicted, fire behavior estimates for hazard appraisal can be acquired. The hazard appraisal program needs debris inputs to perform its calculations.

The hazard appraisal program also accepts the amount of downed woody material that exists in the precut stand and combines it with predicted debris to calculate fire behavior. The amount of debris that exists in the precut stand is not an essential input for the hazard program. If estimates of the amount of debris that exists in the precut stand are not entered in the program, their contribution to fire behavior will be omitted. So, if such debris is expected to be an important influence on fire behavior, estimate or inventory it and enter it in the hazard appraisal program.

BASIS FOR DEBRIS PREDICTION

The debris prediction program gives estimates of weight and volume of potential debris (also termed residue and slash) on areas for which an inventory of trees has been taken. The debris comes from foliage, branches, unmerchantable bole tops, cull trees, and merchantable tree defect (figure 1). This program, or system, estimates debris for each inventoried tree and sums the quantities on a per acre basis.

The debris prediction system was assembled at the Northern Forest Fire Laboratory by James K. Brown (1976). Relationships for predicting debris come from several sources: weights of foliage, branches, and boles of trees less than 4 inches d.b.h., and size class functions for branches, tops, and boles of all trees from data by Brown (1978), unmerchantable top volume from Faurot (1977), boles volumes from equations developed by Al Stage, Intermountain Forest and Range Experiment Station, Moscow; and defect factors from the Northern Region Timber Management Group. Programing was done by Roger McCluskey, Northern Forest Fire Laboratory and Cameron Johnston, Aviation and Fire Management, Northern Region.



DEBRIS IS GENERATED FROM DIFFERENT PARTS OF A TREE

CULL (A) For healthy trees (tree history 1), cull weight is computed by applying cull weight factors to the bole.

(B) For live cull, nonsound, and dead trees (tree history 2 through 8), cull weight is the total weight of the bole.

CROWNS AND TOPS (C) The <3-inch class includes all foliage, live and dead branchwood <3-inch diameter, and the tip portion of the bole less than 3 inches.

<3

>3 The 3-inch and larger class includes all live and dead branchwood and unmerchantable tips 3 inches and larger.

Figure 1.

ACQUIRING THE DEBRIS PRINTOUTS

To predict debris, tree inventory data from a stand exam inventory must be sent to the Regional Office in Missoula for processing. First, the inventory data are edited through a program called R1-EDIT. Errors are flagged and returned to users for correction. After errors are corrected, the data are recorded on the R1-EDIT MASTER TAPE where it is available for analysis of debris potential. A prediction of debris should be requested using an ADP Work Request for Timber Management Programs (form number R-1 2410-15C, 3/76) (fig. 2). Timber staff normally process and edit the stand exam data. Fire staff should coordinate closely with timber staff to acquire the debris prediction printouts. Users may select from three output options:

OPTION 1: Tons per acre for material less than 3 inches in diameter, material 3 inches and greater in diameter, and cull material. This option should be the most frequently used. It is required to operate the hazard appraisal program.

OPTION 2: Tons per acre for needles; branchwood and tops by size classes of less than 0.25 inch, 0.25 to 1 inch, 1 to 3 inches, and 3+ inches; cull material for live, dead sound, and dead unsound trees. This option gives maximum detail, unnecessary for most applications.

OPTION 3: Cubic feet per acre of top and branchwood material 3 inches and larger, and full cull material from live trees, dead sound trees, and dead nonsound trees. This option is primarily for evaluating fiber potential for utilization, using cubic foot units.

In addition to the above options, users must specify a merchantable top diameter limit of 3, 4, or 6 inches that controls the computation of unmerchantable bole top debris. In filling out the ADP Work Request (fig. 2) only one merchantable top diameter limit can be specified for each entry line. Request timber stand tables and debris predictions on separate forms.

DEBRIS PREDICTION DEFINITIONS

Terms that identify debris in the printout headings (table 2) are defined as:

CROWNS Includes needles and living and dead branchwood.

TOPS For trees 4 inches and less in d.b.h., includes the entire bole and for trees greater than 4 inches d.b.h., includes the unmerchantable bole above a specified diameter limit.

USDA-FOREST SERVICE

ADP WORK REQUEST FOR TIMBER MANAGEMENT PROGRAMS

TYPE OF SURVEY:
112 [ ]
145 [X]

Request Only One Type of Program Per Work Request Form

DATE SUBMITTED / /
DATE DESIRED / /
NO. of COPIES

STAND IDENTIFICATION													STAND TABLE PROGRAM										STAND SUMMARY PROGRAM		DFCAL PROGRAM	DEBRIS PREDICTION PROGRAM		
STATE		COUNTY			FOREST		BLOCK OR DISTRICT	COMPARTMENT		SUBCOMP.	SUBUNIT	STAND	TABLE 1	TABLE 2	TABLE 3	TABLE 4	TABLE 5	TABLE 6	TABLE 7	TABLE 8	TABLE 9	TABLE 10	OPTION 1	OPTION 2		OPTION 1	OPTION 2	OPTION 3
1	2	3	4	5	6	7	8	9	10	11	12	13 14	15	16	17	18	19	20	21	22	23	24				25	26	27
16		0	4	9	1	7	8	0	2	9	1	0 7														6		
16		0	4	9	1	7	8	0	2	9	1	0 8														4	4	4

Figure 2. ADP Work Request for Timber Management Programs, R1-2410-15C. Instructions are on the reverse side.

R1-2410-15c(3/76)

INSTRUCTIONS

Heading: Place an "X" in the appropriate box for type of survey. Districts will use the 145 box. Forest Timber Management planners will use the 112 box. Fill in Date Submitted, Date Desired and number of copies needed.

Columns 1 to 14: This is the stand identification for the stand which you want processed.

Columns 15 to 22: Place either a "1" or "2" in the tables column for the table or tables desired. Tables 8, 9, and 10 are always printed for each stand requested.

Code "1" is for Option 1. Only Tree History 1 trees are used.
Code "2" is for Option 2. All live trees used in tables.
Code "3" is for Option 3. All trees inventoried (this is for most fuel management applications).

Table 1 is Basal Area per Acre by Stand Age.
Table 2 is Trees per Acre by Stand Age.
Table 3 is Basal Area per Acre by Species.
Table 4 is Trees per Acre and Average Crown Ratio by Species.
Table 5 is Cubic Foot Growth and Stock Table by Age.
Table 6 is Cubic Foot Growth and Stock Table by Species.
Table 7 is Trees per Acre and Board Foot Volume by Damage/Mortality.
Table 8 is Analysis of Variance.
Table 9 is Site Index for Selected Trees.
Table 10 is Stand Examination and Management Status Record.

Stand Summary Printout: Place an "X" in the appropriate box. Option 1 is based on the 1st and 2nd digit of the Tree Class. Option 2 is based on the 1st and 3rd digit of Tree Class.

DFCAL: Place an "X" in this box if you want the DFCAL printout. Calculates tons per Acre of down and dead fuel by size class and sound and rotten material.

Debris Prediction Program: Specify merchantable top diameter, either 6", 4" or 3" in the boxes for options desired. NOTE: for each stand entry, the top diameter must remain constant for all options.

Option 1: Debris Potential in Tons Per Acre by DBH & Species for (a) Crowns and Tops less than 3" and 3"+ and (b) culls.

Option 2: Same as Option 1, except crowns and tops are broken into five size classes and cull into three types.

Option 3: Debris potential is in Cubic Feet per Acre for crowns and tops greater than 3" and culls.

CULL Includes estimated defect from healthy living trees and 50 to 100 percent of the bole weight exclusive of top pieces for all other trees inventoried as dead and live cull (see table 1).

<3 This size class includes all needles, branches, and top pieces less than 3 inches in diameter.

3, >3 This size class includes all branches and top pieces 3 inches and greater in diameter.

For the different tree history classes used by the Northern Region for categorizing inventoried trees, variable amounts of debris are predicted, as shown in table 1. Tree history refers to tree condition and soundness.

SUMMARIZING DEBRIS BY CUTTING PRESCRIPTIONS

The printouts show the total potential debris per acre, or in other words, the tons per acre of debris that would be created if all trees were cut. Ovendry weights are shown. Green weights, such as found just after cutting, are about twice the dry weights. To find the amount of debris created by some type of partial cutting, the total predicted debris must be reduced to include only trees cut or broken. This can be done by either adding up debris for those trees felled or by subtracting debris from the total for trees left unfelled.

Debris is mostly created by cutting; but, trampling and breakage also create debris. To predict debris for something less than a complete cutting, the amount from each of these sources must be estimated. An explanation of cutting, trampling, and breakage follows:

CUTTING Debris created by cutting trees. The printout shows the maximum amount of cull debris, usually an overestimate because some dead sound trees and boles with defect are hauled to the mill. The cull estimate can be reduced based on local experience with how much dead wood and defect might be hauled from the woods.

TRAMPLING Debris created by logging equipment pushing over small trees. This debris can be estimated from the debris prediction printout for trees less than 5 inches d.b.h. because the total weight of trees this size appears under CROWNS and TOPS. To calculate debris from trampling, estimate the proportion of trees that might be smashed for each d.b.h. class less than 5 inches and multiply the proportion times the potential debris. In stands where trampling creates a significant amount of debris it should be estimated, otherwise it can be omitted.

TABLE 1.--*Contribution of debris for the different tree histories used to classify trees for timber stand inventories in the Northern Region*

Tree history code	Definition of trees	Percent of tree component tabulated as debris			
		Needles	Branches	Tops	Boles
1	All live merchantable trees	100	100	100	[1]0 to 37
2	Live cull <5 inches d.b.h.	100	100	100	100
4, 6	Sound dead ≥5 inches d.b.h., dead more than 5 years, 50 percent or more sound wood	0	40	100	50
5	Sound mortality ≥5 inches d.b.h., dead 5 years or less, 50 percent or more sound wood	100	100	100	50
7	Nonsound dead, any d.b.h., and sound dead <5 inches d.b.h.	0	40	0	100
8	Live cull ≥5 inches d.b.h., less than 50 percent sound	100	100	100	100

[1]Defect factors vary by species and d.b.h. Most typically, they range from 1 to 15 percent but reach a maximum of 37 percent for large hemlock.

BREAKAGE Debris created when trees that appear to be sound break up when felled. Breakage is tough to estimate accurately but in Region 1 it is probably small. To figure breakage, use existing knowledge or local experience and estimate a percent of the inventoried merchantable tree volume that might be left as breakage. Using this percent, figure the cubic foot volume of breakage and multiply by 25 pounds per cubic foot (average density of western conifers) to find weight in pounds. Divide pounds by 2000 to get tons per acre.

Several experienced timber people in Region 1 have stated that breakage ranges from 1 to 10 percent. It probably is greater than 10 percent for species like old-growth hemlock. Breakage due to prop wash during helicopter logging may also exceed 10 percent.

ACCURACY OF DEBRIS PREDICTIONS

Weights are expressed to two decimal places. This is about as accurate as you can get for the crown weight of small trees. Total weights are given to the nearest 1 ton, or to the nearest 5 tons if there is a lot of cull weight. Standard errors often attained with the stand exam inventory and those associated with the debris prediction functions suggest that debris estimates should be within 20 percent of the true mean most of the time. Estimates can deviate from the true mean by as much as 50 percent.

EXAMPLE OF SUMMARIZING DEBRIS

This example shows how to summarize debris from a debris prediction printout (table 2) and STANDTAB tables 4 and 6 (shown in tables 3 and 4). STANDTAB tables are tree summaries from the stand exam. The example also shows how the summarized debris is entered on form R1-5100-4 (fig. 3), that is used as input to the hazard appraisal program. The example, a hypothetical partial cut of grand fir, larch, and spruce, shows all the possible steps in summarizing debris from cutting prescriptions. For many cutting prescriptions such as clearcut, overstory removal, and precommercial thinning, the debris summaries will be simpler than shown in this example. Debris is summarized for cutting, trampling, and breakage as follows:

TABLE 2.--*Sample printout for debris prediction system*

DEBRIS POTENTIAL IN TONS PER ACRE FOR...
STATE 16 COUNTY 49 FOREST 17 BLOCK 8 COMPARTMENT 2 SUBCOMPARTMENT 9 SUBUNIT 1 STAND 7

DBH group	Grand fir			Western larch			Spruce			All species		
	Crowns & tops		Cull	Crowns & tops		Cull	Crowns & tops		Cull	Crowns & tops		Cull
	<3	3,>3		<3	3,>3		<3	3,>3		<3	3,>3	
0- 0.9	0.78	0	0	0	0	0	0.08	0	0	0.86	0	0
1- 1.9	0	0	0	0	0	0	0	0	0	0	0	0
2- 2.9	0	0	0	0	0	0	0	0	0	0	0	0
3- 3.9	0	0	0	0	0	0	0	0	0	0	0	0
4- 4.9	0	0	0	1.28	2.44	0	0	0	0	1.28	2.44	0
5- 5.9	1.52	1.61	0	0	0	0	0	0	0	1.52	1.61	0
6- 6.9	0	0	0	1.18	1.64	0	0	0	0	1.18	1.64	0
7- 7.9	0	0	0	1.04	1.46	0	0	0	0	1.04	1.46	0
8- 8.9	0	0	0	0	0	0	0	0	0	0	0	0
9-10.9	5.92	2.21	4.32	0	0	0	0	0	0	5.92	2.21	4.32
11-12.9	4.35	1.15	3.75	1.72	.70	1.89	0	0	0	6.07	1.85	5.64
13-14.9	3.19	.47	3.06	0	0	0	0	0	0	3.19	.47	3.06
15-16.9	.99	.11	1.05	.72	.17	.87	.87	.10	0	2.58	.38	1.92
17-18.9	1.91	.15	8.64	0	0	0	0	0	0	1.91	.15	8.64
19-24.9	1.01	.08	6.08	0	0	0	0	0	0	1.01	.08	6.08
+25.0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	19.67	5.78	26.90	5.94	6.41	2.76	.95	.10	0	26.56	12.29	29.66
											68.51	

TABLE 3.--*Sample printout for STANDTAB Table 4 that summarizes trees per acre by species for data from a stand exam tree inventory*

TREES PER ACRE BY SPECIES...
FOREST 17 DISTRICT 8 STATE 16 COUNTY 49 COMPARTMENT 2
SUBCOMPARTMENT 9 SUBUNIT 1 STAND 7

DBH group		Grand fir	Western larch	Spruce	Total
0- 0.9	TA	500.0	0	50.0	550.0
1- 1.9	TA	0	0	0	0
2- 2.9	TA	0	0	0	0
3- 3.9	TA	0	0	0	0
4- 4.9	TA	0	50.0	0	50.0
5- 5.9	TA	39.0	0	0	39.0
6- 6.9	TA	0	28.1	0	28.1
7- 7.9	TA	0	24.9	0	24.9
8- 8.9	TA	0	0	0	0
$\frac{27}{67.5}$ = 40% 9-10.9	TA	67.5 Cut 27	0	0	67.5
$\frac{27}{35.8}$ = 76% 11-12.9	TA	35.8 25	19.0	0	54.9
13-14.9	TA	19.8	0	0	19.8
15-16.9	TA	4.7	5.4	4.9	15.0
17-18.9	TA	7.1	0	0	7.2
19-24.9	TA	3.0	0	0	3.0
+25.0	TA	0	0	0	0
TOTAL	TA	676.8	127.4	54.9	859.2

TABLE 4.--*Sample printout for STANDTAB Table 6 that summarizes cubic foot volume for data from a stand exam tree inventory*

CUBIC FOOT GROWTH AND STOCK TABLE BY SPECIES...
FOREST 17 DISTRICT 8 STATE 16 COUNTY 49 COMPARTMENT 2
SUBCOMPARTMENT 9 SUBUNIT 1 STAND 7

DBH	Volume	Species			Total
		Grand fir	Larch	Spruce	
5- 5.9	CFV	73	0	0	73
6- 6.9	CFV	0	124	0	124
7- 7.9	CFV	0	98	0	98
8- 8.9	CFV	0	0	0	0
9-10.9	CFV	40% × 1137 = 455	0	0	1137
11-12.9	CFV	70% × 802 = 561	345	0	1148
13-14.9	CFV	658	0	0	658
15-16.9	CFV	238	197	217	652
17-18.9	CFV	497	0	0	497
19-24.9	CFV	239	0	0	239
+25.0	CFV	0	0	0	0
TOTAL	CFV	3644	765	217	4626

SLASH HAZARD APPRAISAL DATA FORM

PROJECT IDENTIFICATION (up to 48 characters) Example for Users Guide (1-48)

UTIL. STD. (1-10) 6.0 (11-13) ~INCH MERCHANTABLE TOP (blank for precommercial thinning)

HELICOPTER OR SKYLINE SKIDDING (1-10) _____ (PUNCH 1-10) GROUND-LEAD SKIDDING X (OMIT CARD) NO SKIDDING _____ (OMIT CARD) (check one)

LOP DEBRIS (1-10) X (PUNCH 1-10) YES _____ (OMIT CARD) NO

MOISTURE % (1-8) STD _____ (OMIT CARD) 1 Hr _____ (11-13) 10 Hr _____ (14-16) 100 Hr _____ (17-19) 1000 Hr _____ (20-22) Duff _____ (23-25)

1. ENTER LOADING, TONS/ACRE, BY SPECIES AND D.B.H. CLASS, FROM DEBRIS-PREDICTION RESULTS

- D.B.H. classes in inches -

(1-4) Size	(6-8) Spp.	(11-13) 0-1	(14-16) 1-2	(17-19) 2-3	(20-22) 3-4	(23-25) 4-5	(26-28) 5-6	(29-31) 6-7	(32-34) 7-8	(35-37) 8-9	(38-40) 9-11	(41-43) 11-13	(44-46) 13-15	(47-49) 15-17	(50-52) 17-19	(53-55) 19-25	(56-58) 25-30	(59-61) 30+
-3IN	G,F	.39									2.4	3.0	3.2	.99	1.9	1.0		
3+IN	G,F										.88	.81	.47	.11	.15	.08		
CULL	G,F										1.7	2.6	3.1	1.0	8.6	6.1		
-3IN	W,L											1.7		.72				
3+IN	W,L											.70		.17				
CULL	W,L											1.9		.87				
-3IN	E,S	.04												.87				
3+IN	E,S													.10				
CULL																		
-3IN																		
3+IN																		
CULL																		
-3IN																		
+3IN																		
CULL																		
CULL	BKG									2.1								

2. ENTER LOADINGS, TONS/ACRE, BY SIZE CLASS, FROM DOWN-WOODY INVENTORY RESULTS

Size class	0-.25	.25-1	1-3	SOUND 3-6	SOUND 6-10	SOUND 10-20	SOUND 20+	ROTTEN 3-6	ROTTEN 6-10	ROTTEN 10-20	ROTTEN 20+	DUFF
DOWN FUELS (1-10)	.50 (11-13)	1.0 (14-16)	1.5 (17-19)	3.0 (20-22)	5.0 (23-25)	5.0 (26-28)	2.5 (29-31)	(32-34)	(35-37)	(38-40)	(41-43)	1.0 (44-46)

For duff loading, multiply duff depth in inches by 14.5 except for ponderosa pine. For PP duff multiply by 10.0 instead.

GRASS LOAD (1-10) _____ (1 IN CC 11) HEAVY _____ (CC 11 BLANK) MODERATE _____ (OMIT CARD) LITTLE OR NONE (check one)

SLOPE, PCT (1-10) 40. (11-13)

Figure 3. Slash hazard appraisal form R1-5100-4 with correct entries for sample problem. See reverse for instructions.

R1-5100-4 (1/79)

SPECIES CODES FOR SLASH HAZARD APPRAISAL DATA FORM

COMMON NAME(S)	SCIENTIFIC NAME	SPECIES CODE	ALSO USE FOR
Subalpine fir	*Abies lasiocarpa*	AF	
Douglas-fir	*Pseudotsuga menziesii*	DF	
Engelmann spruce	*Picea engelmannii*	ES	
Grand fir	*Abies grandis*	GF	
Lodgepole pine	*Pinus contorta*	LP	
Ponderosa pine Yellow pine Bull pine	*Pinus ponderosa*	PP	
Whitebark pine	*Pinus albicaulus*	WBP	Limber pine
Western hemlock	*Tsuga heterophylla*	WH	Mountain hemlock
Western larch Tamarack	*Larix occidentalis*	WL	Alpine larch
Western redcedar	*Thuja plicata*	WRC	
Western white pine	*Pinus monticola*	WWP	

ENTER NUMERICAL QUANTITIES AS THREE CHARACTERS. EXAMPLES:

123 12. 012 1.2 001 .12 .01 NOTE: 12. AND 012 ARE EQUIVALENT SO ARE 1.0 AND 001

THREE-CHARACTER FORMAT APPLIES TO ALL ENTRIES, INCLUDING MERCHANTABLE TOP STANDARD, DEBRIS LOADING, DOWN-WOODY FUEL LOADINGS, DUFF LOADING, SLOPE, AND MOISTURE

CHARACTER-COUNT FOR PROJECT IDENTIFICATION INCLUDES BLANK SPACES. EXAMPLES:

THIS LINE COUNTS 30 CHARACTERS

AND THIS LINE COUNTS 34 CHARACTERS

E X A M P L E

(Note: The underlined numbers in the following example are the numbers that are entered on form R1-5100-4 (fig. 3). They are entered on form R1-5100-4 rounded to the nearest 0.1 ton/acre.)

CUTTING

Grand fir prescription.--Through contact with the District timber staff, the following trees were found marked for removal:

(1) 40 percent of the 9 - 10.9 inch d.b.h. class
(2) 70 percent of the 11 - 12.9 inch d.b.h. class
(3) 100 percent of all trees 13.0 inches and larger

This results in cutting 27 trees in the 10-inch class, 25 trees in the 12-inch class, and all trees larger than 13 inches d.b.h. on a per acre basis. Using this information and the debris printout (table 2), the debris potential is:

		Tons/acre		
		<3	3,>3	Cull
9.0 - 10.9 inches d.b.h.: 40 percent of 5.92, 2.21, and 4.32	=	2.37	0.88	1.73
These weights are rounded to the nearest 0.1 ton/acre and transferred to form R1-5100-4 (fig. 3)				
11 - 12.9 inches d.b.h.: 70 percent of 4.35, 1.15, and 3.75	=	3.05	.81	2.63
These weights are transferred to form R1-5100-4 (3.05 = 3.0, etc.).				
≥13.0 inches d.b.h.: 3.19 + 0.99 + 1.91 + 1.01	=	7.10		
0.47 + 0.11 + 0.15 + 0.08	=		.81	
3.06 + 1.05 + 8.64 + 6.08	=			18.83

In transferring the above to form R1-5100-4, round and enter individually for each d.b.h. class. Do not group d.b.h. classes.

Larch prescription.--Remove all trees ≥11 inches d.b.h.:

		Tons/acre		
		<3	3,>3	Cull
1.72 + 0.72	=	2.44		
0.70 + 0.17	=		0.87	
1.89 + 0.87	=			2.76

Again, in transferring to form R1-5100-4, enter debris in each d.b.h. class, do not group.

Spruce prescription.--Remove all trees.

≥9 inches d.b.h.	=	0.87	0.10	
TOTAL DEBRIS FROM CUTTING	=	15.83	3.47	25.95

TRAMPLING

Based on personal estimation of 50 percent of all grand fir and spruce trees <4 inches d.b.h.

Grand fir: 0.5 x 0.78	=	0.39
Spruce : 0.5 x 0.08	=	0.04
TOTAL DEBRIS FROM TRAMPLING	=	0.43

Transfer directly to form R1-5100-4 by species.

BREAKAGE

For this example, assume 5 percent for all species. From STANDTAB 6 (table 4), cut tree volumes are:

Grand fir: (0.4 x 1,137 = 455) + (0.7 x 802 = 561) + 658 + 238 + 497 + 239	= 2,648 ft^3
Larch : 345 + 197	= 542 ft^3
Spruce : 217	= 217 ft^3
Total :	= 3,407 ft^3

Estimated volume breakage = 0.05 x 3,407	=	170 ft^3
Average density of western conifers	=	25 lbs/ft^3
Estimated weight = 170 x 25	=	4,250 lb or 2.13 tons/acre

Round to nearest 0.1 tons/acre and enter this weight on form R1-5100-4 in the row labeled BKG and the column for the 8 - 9 inch d.b.h. class

SUMMARY

	Tons/acre		
	<3	3,>3	Cull
Debris from cutting	15.83	3.47	25.95
Debris from trampling	0.43		
Debris from breakage			2.13
Total (47.75 or 48 tons/acre)	16.25	3.47	28.03

The procedures for summarizing debris will extend to any cutting situation. For example, debris created from thinnings and overstory removals is calculated in the same way as in the partial cut example. Clearcut treatments involve transposing the DEBMOD printout to the R1-5100-4 form.

COMPLETING THE HAZARD FORM

Form R1-5100-4 (fig. 3) is the HAZARD input form and is more or less reversed in format from the debris prediction printout to speed up key punching. The form provides for two types of input: (1) debris, and (2) site and other fuel information. Consult the back of form R1-5100-4 for coding instructions and fill it out as follows:

Project Identification. -- Use any desired description up to 48 characters.

Utilization Standard. -- Record the merchantable top diameter limit to the nearest whole inch or tenth of an inch, such as 6.0. Record 0 or leave blank for precommercial thinning.

Method of Skidding. --Check the method of skidding that is most like the method used. Precommercial thinning is denoted by no skidding. Ground lead skidding includes methods such as tractor, jammer, and high lead.

Lopping. -- If the effect of lopping on fire behavior is desired as output, check yes; otherwise, check no.

Fuel Moisture. -- Fuel moisture content may be specified by the user or left for the HAZARD Program to specify. On the data form, any unspecified (blank or zero) entries will be replaced by the prestored values in the program. The values should be entered to the nearest whole percent, in the 3 blank spaces allotted for each number. (For example: 9.0 or 10.) The quantities that can be specified and their prestored values are:

FUEL COMPONENT	PRESTORED MOISTURE, PCT	REMARKS
1-HR TIMELAG	5	Used for grass* (if any), foliage**, and 0-1/4 inch woody fuels.
10-HR TIMELAG	7	Used for 1/4-1 inch woody fuels.
100-HR TIMELAG	9	Used for 1-3 inch woody fuels.
1000-HR TIMELAG	12	Used for 3+ inch woody fuels.
DUFF	20	Average for L+F layers combined.

*Only dead grass is to be input to HAZARD. If there is mostly live grass on site, specify Little or None.

**Program will not handle fresh slash with a high foliage moisture content.

Things to watch out for when specifying fuel moisture values to be used . . .

1. Specify moisture contents as percent, to nearest whole percent.

2. Blank or zero values entered will be ignored, and prestored values substituted for missing entries.

3. The program computes a weighted average fuel moisture content that is very heavily weighted by the one-hour timelag fuel moisture. This weighted average value is compared to a "limit" value that depends on fuel bed compactness. If the weighted average moisture content exceeds this limit value, the model predicts no fire spread. You may find such a notice printed out when you run the program using specified (rather than preset) moisture values. This should not be interpreted literally as "No fire will spread here" but rather as "The fine fuel moisture is so high that model predictions are a poor guide to burning conditions." In this case, however, if slash is the dominant fuel, fire should be expected to spread very slowly.

4. In fire modeling neither 1000-hr timelag fuel moisture or "duff" fuel moisture affects fire behavior for the spreading fire. The longer-term residual fire, as reflected in burning time and heat load figures, is strongly influenced by these moistures and only weakly affected by the finer-fuel moistures.

5. The word "duff" refers to the combined L and F layers of the forest floor, excluding the H layer. The moisture content represents the average moisture content of these two strata, treated as a whole.

Debris Prediction.--Transfer debris weights from the debris prediction printout as shown in the example. Be sure breakage is recorded in the "BKG" row and in the column for the 8- to 9-inch d.b.h. class, which approximates the diameter of broken boles. One data form will handle five species. Use more forms if you have more than five species. The 11 species of western conifers for which predictions can be made are listed on the back of form R1-5100-4 (figure 3). When two or three forms are used, complete the lower part (downed woody fuel, grass, and slope) on only the last form. Record breakage only once--on last form--if more than one form is used. Recording 3+ material that appears on the debris prediction printout for d.b.h. less than 1 inch (latched areas) is unnecessary because of the very small amounts involved. Species of tree is indicated by a two or three letter code (see back of form R1-5100-4 for code key). There is space to enter three letters in the column labeled Spp. When a two letter code is used, start in the left most space available, leaving the last space blank.

Downed Woody Material.--Loadings of downed woody material prior to cutting should be entered on the form. Be sure loadings are entered as shown in the coding instructions. Loadings of downed woody material can be inventoried and the data processed in either of two ways:

1. Using the stand exam inventory form 2410-15B, both standing trees and downed woody material can be inventoried. A printout of processed data can be requested on form 2410-15C (figure 2).

2. Using the downed woody inventory form R1-5100-7 and procedures described in Handbook for Inventorying Downed Woody Material (Brown 1974). The data are processed by computer (Program DFINV) in Fort Collins, using National Forest computer terminals. This option offers rapid turnaround of processed data.

Amount of Grass.--This permits the effect of grass and sedge fuels on fire behavior to be considered. Amounts will be small or moderate on average sites; heavy on very grassy sites.

Average Slope.--Enter the average slope to the nearest 10 percent.

Completed forms can be sent to either the Forest computer specialist or technician or to the Regional Office ADP Section for processing.

OTHER DEBRIS PREDICTION METHODS

The debris prediction program, DEBMOD, described in this guide is the most accurate method for predicting slash fuels because crown and bole weights are estimated on a tree-by-tree basis. It should be used when possible. However, another method for predicting debris also exists and may have application in some situations. This method and its strengths and limitations are:

Hand calculation using tables.--Amounts of potential debris can be figured by hand using the publication:

Brown, James K., J.A. Kendall Snell, and David L. Bunnell. 1977. Handbook for predicting slash weight of western conifers. USDA For. Serv. Gen. Tech. Rep. INT-37, 35 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

The calculations require knowledge of the number of trees per acre or basal area per acre to be cut, by species and d.b.h. This handbook is best applied when a stand exam has not been taken or will not be processed in time to meet information needs. Debris from small salvage sales and hypothetical cuttings perhaps can be determined most conveniently using this handbook.

SUMMARY OF STEPS TO PREDICT DEBRIS

Figure 4 is an outline of the steps required to predict debris volumes and fire behavior. The first step is to conduct a stand exam inventory. A downed woody inventory is nice but not essential, unless significant amounts of debris are present in the precut stand. Next, the field data are edited with help of a Northern Region computer program, R-1 EDIT. Gathering field data and processing it through the R1-EDIT is the most time-consuming step in this sequence. This is normally handled by timber staff and is outlined and described in the R1-STAND EXAMINATION HANDBOOK, January 1977.

After data are edited (and entered on master tape), fill out ADP Work Request form 2410-15C and submit to the ADP Section at the Regional Office to acquire information from:

1. DEBMOD : Debris prediction options 1, 2, or 3
2. DFCAL : Downed woody inventory from stand exam
3. STANDTAB : Tree summaries
4. STAND SUMMARY: Tree summaries options 1 or 2

DEBMOD and DFCAL are fire-oriented programs, while STANDTAB and STAND SUMMARY are timber programs. Program DEBMOD predicts debris from the standing trees recorded in the stand exam, and program DFCAL calculates existing downed debris.

Once debris prediction and downed woody printouts are obtained, debris can be summarized by cutting prescriptions. Consult with timber staff about the silvicultural prescriptions.

Finally, request the hazard appraisal program by filling out form R1-5100-4. The weights entered on the 5100-4 form are summarized from the debris prediction and downed woody printouts. Get the downed woody printouts from the Regional Office if form 2410-15B was used and from the Supervisor's Office if form 5100-7 was used. Send the completed 5100-4 form to the Regional Office, or to the Computer Specialist at the Supervisor's Office.

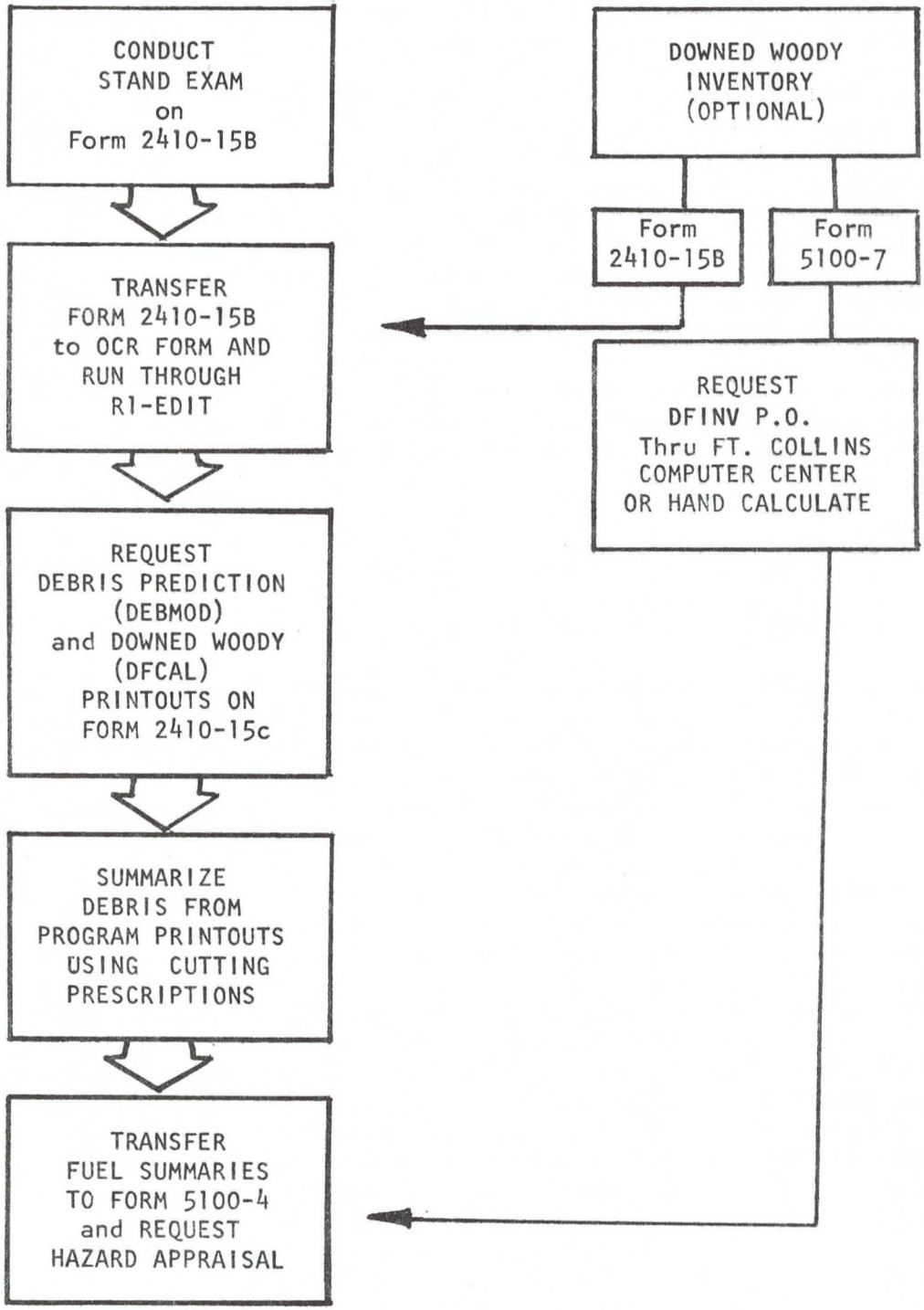


Figure 4. Schematic outlining steps required to predict debris volumes and fire behavior.

III. EXPLANATION OF FUEL AND FIRE OUTPUTS

This section describes the output of the HAZARD program. The implications of the HAZARD output must be assessed case by case to insure that the information is properly applied.

The output from the hazard appraisal program consists of two parts. The first part restates the debris prediction and the downed woody inventory data so it can be verified (table 5). The slope and the grass loading are also displayed. A 5-year history of fuel bed depth, both for untreated and lopped conditions, is shown. Lopping is presumed done to a "2-foot standard." That is, no limbs extend more than 2 feet off the ground, and no tree boles or large limbs lay more than 1 foot off the ground.

The second part of the output consists of one or two tables of numbers that describe potential fire behavior. The first table is for untreated debris; the second for lopped debris, if lopping is specified for display.

FUEL

The first block of fuel numbers lists the input data from the 5100-4 form, as shown in table 5. The input is reprinted so the user can verify the data that formed the basis for the output. To emphasize this point, a space is provided on the first page of the output for the user to initial. The downed woody inventory data input to the program are also shown and should be checked by the user.

The hazard program projects the initial fuel loading data ahead in time for 5 years. During this time, needles and 0- to 1/4-inch twig loadings are reduced. Needle loss is not shown in the output data, but the effect of settling (reduction in depth) is. Because of its importance in determining fire behavior and because so many factors influence it, a special research project was undertaken to find out how to predict the depth of debris. The relationships in the HAZARD model reflect the best available data at the time of this writing. They are subject to change.

The fuel depths shown in the outputs may be lower than expected. Visual estimates of depth are almost always high, because the eye tends to focus on the highest points of the debris. The hazard appraisal program computes the fuel depth that would be observed if the fuel were uniformly spread over the site. Thus, prominent single limbs or tops standing above the average height are discounted, and the depth of a uniform fuel bed of the same average loading and compactness is calculated.

TABLE 5.--*Restatement of input data, Hazard Appraisal Program*

ACTIVITY FUEL FIRE HAZARD ASSESSMENT

INPUT SUBMITTED BY.....

OUTPUT CHECKED BY.....

EXAMPLE FOR USERS GUIDE

DATE.....

DEBRIS-PREDICTION INPUT DATA ...

SIZE	SPE-CIES	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-11	11-13	13-15	15-17	17-19	19-25	25-30	30+
		LOADING (T/A) BY DBH CLASS																
-3IN	GF	.39	.00	.00	.00	.00	.00	.00	.00	.00	2.40	3.00	3.20	.99	1.90	1.00	.00	.00
3+IN	GF	.00	.00	.00	.00	.00	.00	.00	.00	.00	.88	.81	.47	.11	.15	.08	.00	.00
CULI	GF	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.70	2.60	3.10	1.00	8.60	6.10	.00	.00
-3IN	WL	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.70	.00	.72	.00	.00	.00	.00
3+IN	WL	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.70	.00	.17	.00	.00	.00	.00
CULI	WL	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.90	.00	.87	.00	.00	.00	.00
-3IN	ES	.04	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.87	.00	.00	.00	.00
3+IN	ES	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.10	.00	.00	.00	.00
CULI	BKG	.00	.00	.00	.00	.00	.00	.00	.00	2.10	.00	.00	.00	.00	.00	.00	.00	.00

ACTIVITY-PRODUCED FUELS ... 3 IN AND LESS = 15.9 ... OVER 3 IN = 31.5 ... TOTAL = 47.4

AVG FUEL DEPTH, FT	NUMBER OF WINTERS 1	2	3	4	5
UNTREATED SLASH	1.12	1.12	1.12	.96	.81
LOPPED TO 2-FT STD	.94	.94	.94	.82	.69

DOWN-WOODY INVENTORY ...

	LOADING IN TONS/ACRE 1 HR	10HR	100H	3-5	6-9	1020	20 +			
DOWN SOUND	.5	1.0	1.5	3.0	5.0	5.0	2.5	3 IN AND LESS =	3.0 ...	TOTAL = 18.5
DOWN ROTTEN				.0	.0	.0	.0		...	TOTAL = .0

OTHER INPUT DATA ...

NOMINAL GRASS LOADING = .0 MEASURED DUFF LOADING = 10.0 AVERAGE SLOPE (PERCENT) = 40

FUEL MOISTURE FOR (PERCENT DRY WT.)	1 HR	10 HR	100 HR	1000 HR	DUFF
	5.	7.	9.	12.	20.

ACTIVITY ... GROUND-LEAD TIMBER HARVEST UTILIZATION STANDARD = 6.0 INCH TOP RUN 05 DEC 78

TABLE 6.--*Fire behavior outputs, hazard appraisal program.*

EXAMPLE FOR USERS GUIDE
UNTREATED SLASH
POTENTIAL FIRE BEHAVIOR

QUANTITY ASSESSED	20-FT. WIND MI/H	SLASH AGE IN NUMBER OF WINTERS 1	3	5
.....	0	4	3	1
HEAD FIRE	5	7	5	3
SPREAD RATE	10	12	8	4
CHAINS/HOUR	15	19	13	6
.....	20	27	18	8
.....	0	15	11	6
PERIMETER	5	24	17	10
GROWTH RATE	10	36	24	13
CHAINS/HOUR	15	47	31	16
.....	20	57	37	17
.....	0	2	1	0
BURNED AREA	5	5	2	1
AFTER 1 HOUR	10	11	5	1
BURN, ACRES	15	20	9	2
.....	20	29	12	3
.....	0	6	5	3
HEAD FIRE	5	9	7	5
FLAME LENGTH	10	11	8	6
IN FEET	15	14	10	7
.....	20	16	12	8
.....	0	47	31	19
CROWN SCORCH	5	65	41	22
HEIGHT IN FT	10	76	43	18
BY HEAD FIRE	15	82	42	16
.....	20	86	42	14
.....	0	324	176	81
INTENSITY AT	5	600	335	158
HEAD OF FIRE	10	1081	584	254
(BTU/SEC/FT)	15	1688	885	358
.....	20	2395	1224	468

RESIDUAL FIRE FROM BURNOUT OF LARGER FUELS (AND DUFF)

HEAT LOAD (BTU/SQFT)	16006	14775	13920
BURN TIME (MINUTES)	76	76	76

GRL. LEAD HARVEST UTL. STD. 6.0 IN RUN 05 DEC 78

For users inputting their own fuel moistures, refer to the section on Completing the Hazard Form for a discussion of the meaning of fuel moisture terms.

FIRE BEHAVIOR

Potential fire behavior is assessed for windspeeds of 0, 5, 10, 15, and 20 mi/h (at standard 20' anemometer exposure) and for debris ages of 1, 3, and 5 years. The first table is for untreated debris (table 6); the second (if required) is for lopped debris. Table format is the same.

Fire behavior variables presented in the tables are based on an upslope wind and upslope fire spread. Limitations and accuracy of the fire behavior values are discussed in the next section.

The following descriptions and comparative values will help the user interpret and discuss the significance of the fire behavior numbers:

1. *Head fire rate of spread (chains/h)*.--The values under this heading are maximum rates, rounded to the nearest chain/hour; the wind is blowing directly upslope, and the fire is advancing upslope. For comparison purposes, note the following equivalent rates of progress:

- 1 chain/h is about the rate of fireline construction for one man using hand tools in medium fuels (medium resistance to control).

- 10 chains/h is about the rate of fireline construction for a bulldozer working in fuels of extreme resistance to control.

- 100 chains/h is about the speed of a leisurely stroll on level terrain or a good average pace for backpacking in medium to steep terrain.

2. *Perimeter growth rate (chains/h)*.--Under the conditions cited above, this value is an estimate of the rate of increase in the length of a smooth elliptical outline marking the advancing edge of a fire started at a point (e.g., a spot fire) in the debris. The perimeter growth rate can be viewed as a rough indication of the minimum total line-building rate required to contain a fire.

3. *Area burned in 1 hour (acres)*.--These values give the area burned after 1 hour. This area can be used to predict how long a fire that starts in the debris will stay in the debris. Burned area increases with the square of the burning time. To predict the time a fire could stay in the cutting unit, divide half the area of the cutting unit by the area burned in 1 hour and take the square root. The result will be the time, in hours, that one could expect the fire to be burning mostly in the cutting unit debris. After this period of time, a fire started in the unit would probably have burned out of it into adjacent fuels.

4. *Headfire flame length (feet)*.--This is the length of flame from the center of the flaming zone at the upper surface of the fuel bed to the tip of the flame. This dimension, with no wind, will be the vertical flame height. In most cases, wind will tilt the flame and the flame length will be the slant distance. Guides for interpreting flame length are included under item 6, below.

5. *Crown scorch height due to head fire (feet)*.--Crown scorch height is calculated from Byram's intensity (see item 6, below). The scorch height value represents the height at which a lethal temperature of 140° F or greater is reached above a spreading head fire. Values are rounded to the nearest foot and assume an ambient temperature of 77° F. While it is possible to adjust for other ambient temperatures (Albini 1976), the accuracy of the estimate in itself does not warrant such a refinement. Lethal scorching implies that the tissue is killed; the scorched needles will turn brown within a few weeks. Cambium kill due to heating alone (with or without crown scorch) is not modeled in this program. Thus, the user should be aware that tree kill may be underestimated if only crown scorch damage is considered. Tree kill from crown scorch may also be underestimated if slope is greater than 50 percent.

6. *Byram's intensity for the head fire (Btu/s/foot)*.--This quantity represents the rate of heat release per foot of fire edge at the head of the running fire. It has been used to describe the difficulty of controlling a fire. The list that follows shows numerical values and associated descriptions that may help to interpret this quantity. The flame length (item 4, above) derived for each intensity from Byram's formula is also shown.

Byram's intensity	Flame length	Fire situation
≤5 Btu/s/foot	≤1 ft	Marginal burning. Few fires exist at this level.
20 - 50 Btu/s/ft	2 - 3 ft	Easily attacked and controlled. People can work right up to the edge of the fire without extra protection.
100 Btu/s/ft	4 ft	This is about the limit beyond which people are unable to work at the fire edge. Direct attack with hand crews may be difficult.
500 - 700 Btu/s/ft	8 - 9 ft	Spotting begins to be a problem and the limit of direct attack is probably reached in this range of intensities.

Byram's intensity	Flame length	Fire Situation
1,000 Btu/s/ft	11 ft	Crowning can be expected to begin. Serious spotting may occur.
20,000 - 30,000 Btu/s/ft	40 - 50 ft	Major conflagration. Long-range spotting occurs; tree blowdown may occur. Flaming zone depths of up to 1/4 mile can arise, so the flame length formula is not very useful here.

7. *Heat load (Btu per square foot)*.--This number represents the total heat release per square foot of surface due to the burning of surface fuels, litter, and duff. It measures the potential combustion energy stored on the site. To interpret this quantity as anything other than an index of fuel accumulation cannot be supported at this time. From physical principles it seems nearly certain that such effects as soil conditioning, seed treatment, root damage, etc., should be related to total energy release on the burned site. Users need to observe vegetative response and other site effects from fires of different heat loads. In this way, a basis for interpreting heat load values can be acquired.

8. *Burn time (minutes)*.--This gives a rough estimate of the period of active flaming at the fire front, not the duration of smoldering or the burning time of concentrations of debris. By itself, the burn time is probably not a useful number because it is not related to fire intensity. Used with the heat load value (see item 7, above), we can interpret this number as an indicator of the time after passage of the fire front when people could enter the burned area.

When the heat load is divided by the burn time, the result is an estimate of the rate of heat release per unit area, a measure of fire intensity. Based on the temperature of a flame tip, a fire burning in natural fuels emits about 100 Btu/min/ft^2. From this we can infer that a ratio of heat load to burn time of about 100 would represent a hazardous situation for firefighting ground crews. This value, like any other average value, must be interpreted in relation to what is on the ground. If debris is spread rather uniformly over the area a value as low as 10 might indicate a hazardous situation. But if debris tends to be concentrated in piles safe entry might be permitted despite values in excess of 100.

LIMITATIONS AND ACCURACY

The hazard appraisal program, in its present form, is intended to be used in planning. The numbers produced by the hazard program must be interpreted by trained people. In this way, the absolute values can be reduced to indexes that mean something--or even adjective ratings. The greatest strength of the hazard appraisal program is in providing an objective means of using fuel estimates in a planning exercise. Because the program uses new research, the absolute values are often not all that accurate. Some are more accurate than others, for example: rate of spread and intensity are probably the most reliable numbers provided. Limitations of the program and estimates of the accuracy of the predictions are given in the remainder of this section.

The program was not designed for the establishment of prescriptions for treatment of debris by burning. For recommendations and guidelines for establishing such prescriptions refer to:

1. Prescribed Burning Guides, by USDA-Forest Service, Northern Region.

2. Preliminary Guidelines for Prescribed Burning Under Standing Timber in Western Larch/Douglas-Fir Forests, by Rod Norum (1977), Intermountain Forest and Range Experiment Station.

3. Planning and Evaluating Prescribed Fires - A Standard Procedure, by Bill Fischer (1978), Intermountain Forest and Range Experiment Station.

Basic Assumptions

The following assumptions are made in the formulation of the fire behavior prediction equations. They should be kept in mind when using the fire behavior numbers.

1. Predicted debris represents the dominant fire-carrying fuels on the site. The computer has no way of knowing if this assumption is, in fact, true for the situation being evaluated by the user. If fuels other than those used as inputs to the hazard program, such as shrubs from shrub dominated habitat types, are likely to have a significant influence in the stand after cutting, the fire behavior predictions must be discounted accordingly.

2. Living vegetation on the site (which may either enhance or hinder the rate of fire spread and increase or decrease fire intensity) is not considered in the program. The effect of conifer reproduction can be approximated, however, by including small trees (from the debris potential output) in the input to the hazard appraisal program. If grass, forbs, or living shrubs are important to fire behavior on the site, other methods of estimating fire behavior such as the fire behavior nomograms provided by Albini (1976) must be employed.

3. The debris is assumed to be spread uniformly over the site. Fuel accumulations, whether due to intentional piling, incidental windrowing (e.g., along skid lanes) or chance "jackpot" concentrations often occur. Fire in these atypical loadings will not behave in the same way as will fire in the "average" loading. This source of variation in fire behavior may differ greatly from site to site. The user must use judgment to assess this variation.

Accuracy of Predictions

The accuracy of the fire behavior values is not as great as that of the debris prediction values. In other words the user should not expect predicted fire behavior values to be absolute indicators of the values that would be observed on an actual fire under comparable conditions. The predictions should, none the less, provide approximate values likely to be observed on an actual fire under comparable conditions. This caution is not meant to discourage use of the fire behavior numbers. Just remember, the power of the Hazard Appraisal Program is in the magnitude and the relative nature of the predicted fire behavior numbers, not their absolute value.

The accuracy of fire behavior predictions depends on the accuracy of the fuel input (debris prediction) and of the fire behavior models used in the computer programs. A summary of the accuracy of the predictions based only on these factors follows:

1. *Head fire rate of spread*.--Deviations from the predicted values should be expected, even when input data are representative of the actual conditions. A range of actual spread rates from 1/2 to 2 times the predicted values is to be expected. Once in a while values of from 1/4 to 4 times the predicted values will occur. Only very rarely should the actual value be less than 1/10 or more than 10 times the prediction.

2. *Permimeter growth rate*.--Only a few lab tests and a limited number of field examples provide the basis for the perimeter growth rate calculation. Prediction of this growth rate depends on calculation of rate of spread, and the accuracy of this spread rate contributes the greatest uncertainty. Thus, the accuracy of the perimeter growth rate is about the same as for rate of spread (see item 1, above). The perimeter estimated here is the smooth outline

of a roughly elliptical shape. It in no way is meant to reflect the details of a ragged outline of an actual fire.

3. *Area burned in 1 hour.*--The basis for this calculation is the same as for the perimeter growth item (item 2, above), so the cautions listed above apply. The area burned over in a given time is proportional to the square of the forward rate of spread. Therefore, the uncertainty in the value of the computed burned area is amplified by this relationship of spread rate and area. Deviations from predicted values in the range 1/4 to 4 times are to be expected, and variations within the extremes of 1/10 to 10 times the predicted value should occur once in a while.

4. *Flame length at the head of the fire.*--The head fire flame length is calculated from the head fire of Byram's intensity. The length of the flame is different from its vertical height or its horizontal reach, and the value given is an average estimate, not a maximum or minimum. Flame length will have an accuracy that should be about the same as for rate of spread. That is, it can be expected to vary from 1/2 to 2 times the value given. Flame lengths less than 2 feet imply debris is likely not the main fire carrier. The user should check to see if grass, shrubs, litter, or dead fuels not entered in the program are prevalent on the site.

5. *Crown scorch height due to head fire.*--Although meant to imply a maximum scorch height, lethal scorching above the calculated scorch height can occur. Predictions of crown scorch height and their accuracy depend on fuel amount and how the fuel is distributed over the area. Variations away from the assumption of uniform fuels used in the model will cause inaccuracies. These inaccuracies should be about the same as for flame length and rate of spread.

When comparing scorch height and flame length, remember that flame length may be a slant measurement and not a vertical height measurement. Under high wind, flame length may exceed scorch height because heat is being carried away rather than rising up to the tree crowns.

If the slope is 50 percent or greater, the scorch height may be badly underestimated; crown scorch may occur a significant distance upslope from the burned area. Additional tree damage can occur through cambium kill and/or root damage. While no attempt has been made to model these effects, the user may find the total heat load figure (see item 7, below) a useful guide to inferring the potential for such damage.

6. *Byram's intensity for the head fire.*--The theory behind this calculation is sound. It is based upon knowing head fire rate of spread so accuracies in the intensity will be the same as expected for rate of spread.

7. *Heat load*.--The theory for heat release per unit area was developed from available data. More work needs to be done so results should be used with caution. Heat load is highly sensitive to duff moisture so consumption of duff and surface fuels will vary accordingly. For the average duff moisture of 25 percent, as assumed in the program, the heat load value is expected to be accurate to about ±40 percent.

8. *Burn time*.--The formula used for this calculation is based on empirical data described in research literature. The figure is probably accurate to ±40 percent, but no direct evidence of precision is available. More work is needed so use with caution.

When forming the ratio of heat load to burn time, the result should be viewed as an estimate that can, with equal likelihood, be 1/2 to 2 times the value it should be.

VI. SUMMARY

This guide describes a technique for predicting, in advance of cutting, the amount of debris likely to result from planned forestry operations. Then, the technique takes the debris prediction and calculates its potential fire behavior under varying weather conditions. By using the guides for interpreting the fire behavior numbers, along with some experienced judgment, the manager can come up with a hazard appraisal for the proposed project.

The technique is especially well-suited for describing the differences in the amount of debris and fire hazard between various stand treatment options.

If used with an appreciation of its limitation, the debris prediction and hazard appraisal technique can aid the manager in making better fuel management decisions than he can make on the basis of experienced judgment alone.

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